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# (12) UK Patent Application (19) GB (11) 2 144 561 A

(43) Application published 6 Mar 1985

(21) Application No 8410158

(22) Date of filing 18 Apr 1984

(30) Priority data

(31) 487116

(32) 21 Apr 1983

(33) US

487117

21 Apr 1983

487118

21 Apr 1983

(51) INT CL<sup>4</sup>

G05D 25/02 A61N 5/06 G02B 7/00

(52) Domestic classification

G3R A273 A28 A624 B352 BK

G2J 32 RB2

H1C 202 210 341 34Y 351 35Y 392 402 A

U1S 1029 1032 G3R H1C

(56) Documents cited

GB 1414686

GB 1379609

(58) Field of search

G3R

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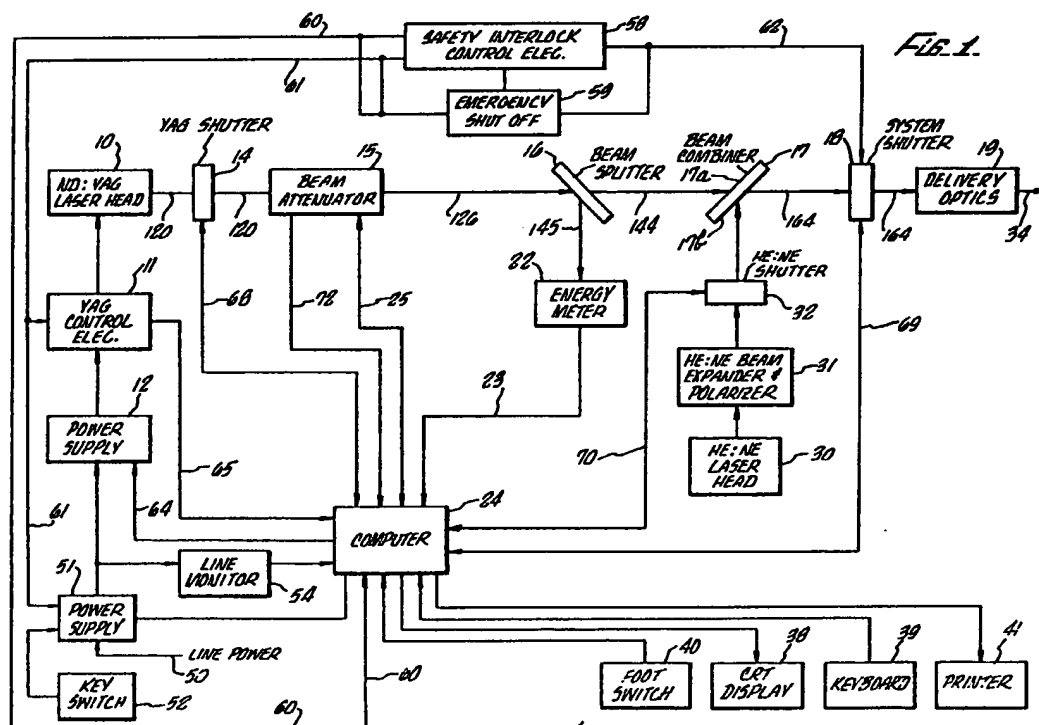
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## (54) Laser system

(57) In a laser system for treatment, e.g. to the eye, the beam from a ND: YAG laser 10 is attenuated at 15 under the control of a computer 24 in response to the energy of the beam measured at 22. The computer compares the energy with a desired value initially during a calibrating operation while a shutter 18 (see Fig. 2C) is closed and periodically thereafter. For aiming and viewing a second laser 30 is provided (HE: NE type) whose beam is combined with the treatment beam at 17.

A table for mounting the optical system is also disclosed (see Fig. 5B).



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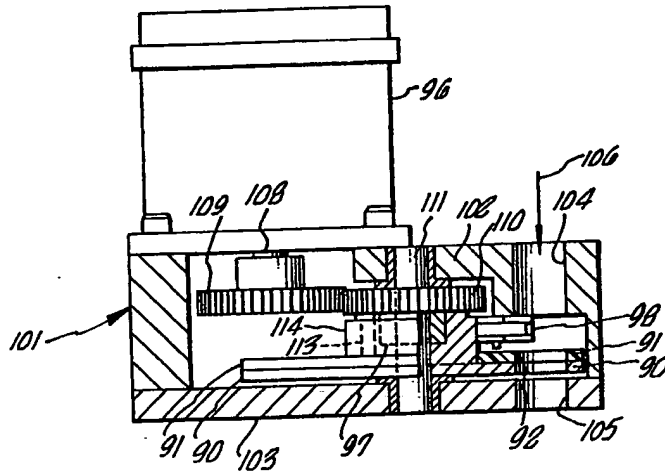


FIG. 2A.

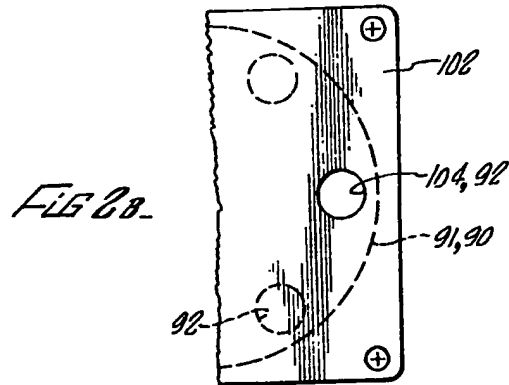


FIG. 2B.

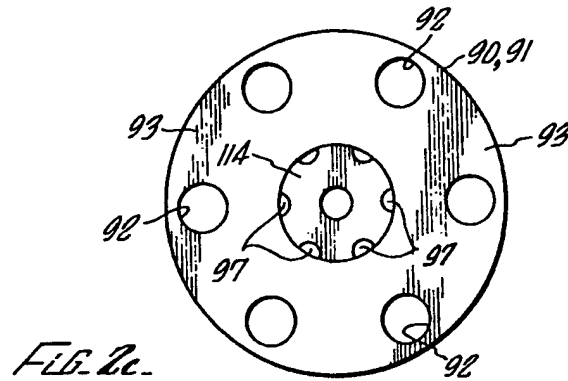


FIG. 2C.

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FIG. 3A.

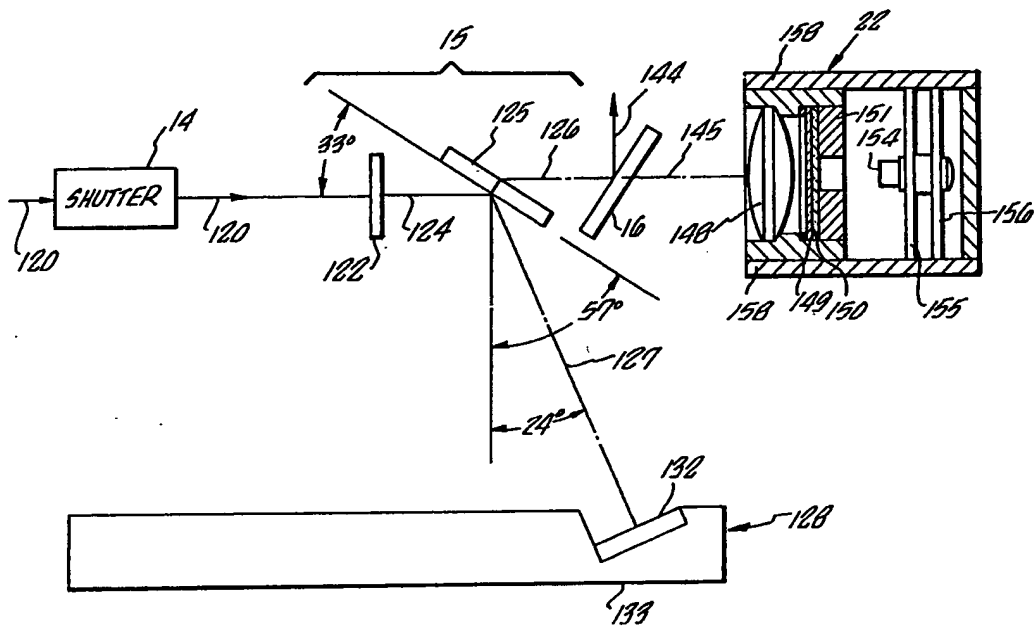
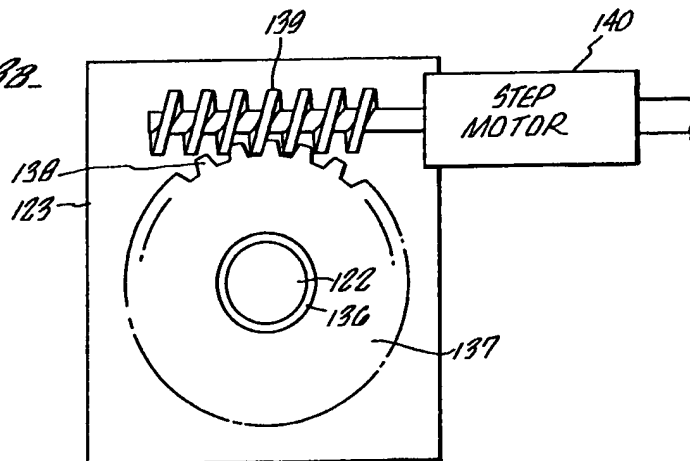
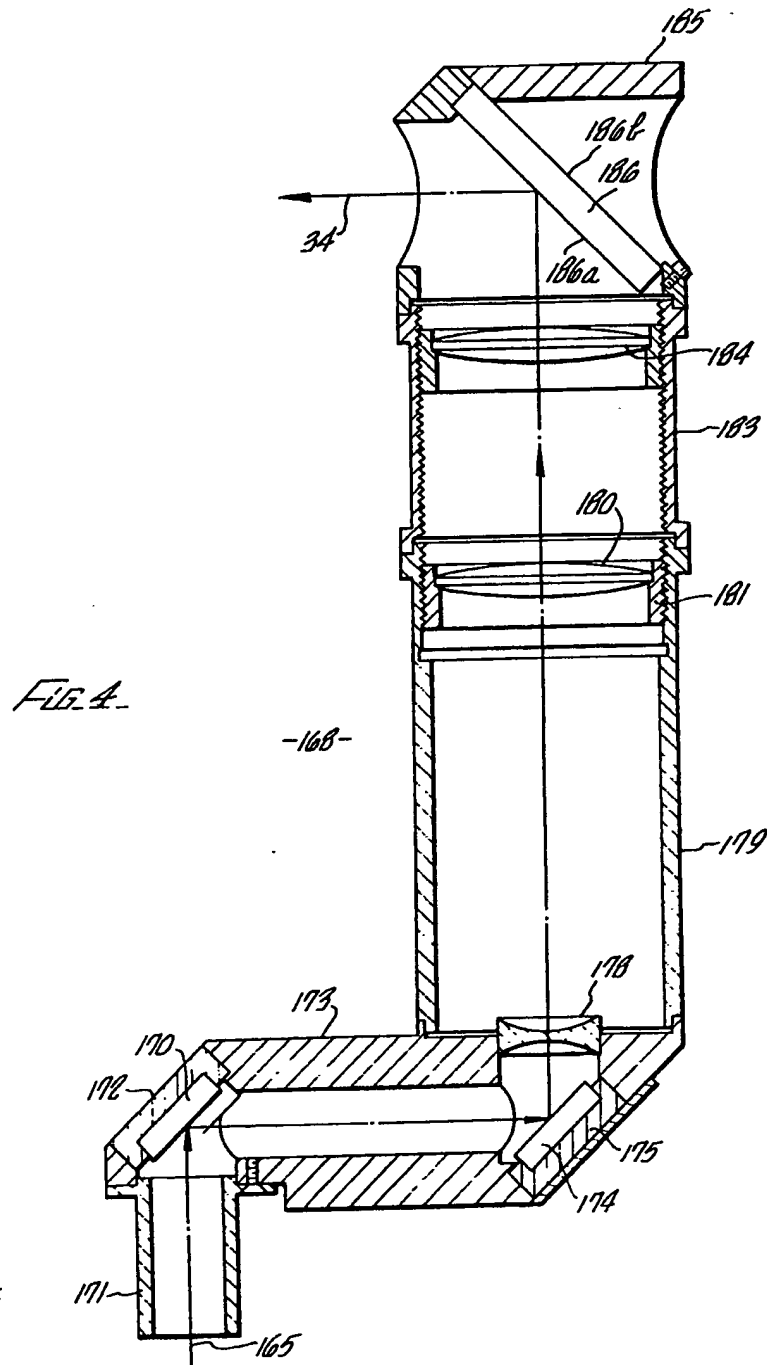


FIG. 3B.



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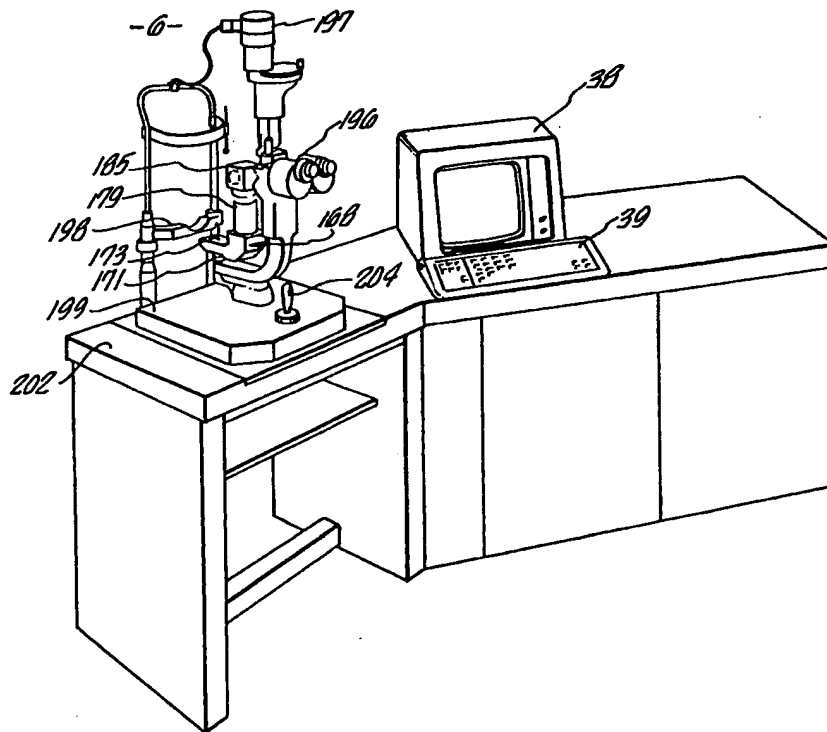


FIG. 5A.



## SPECIFICATION

## Laser system

5 The present invention relates to laser systems, and more particularly to a closed loop laser system particularly useful for laser surgery, more particularly eye surgery and like procedures.

10 The most common use of lasers in ophthalmology is as photocoagulators. This use of the laser evolved from the use of the Xenon-arc lamp. Lasers were studied for replacing the Xenon units which required high exposure times of one-fourth to one second, creating the need for retrobulbar anesthesia due to the pain. The first laser photocoagulators were ruby lasers producing red light of 694 nm, and were utilized to treat retinal tears. This laser was found to have the additional feature of reduced heating of the ocular media and a small focal spot. Ruby lasers were replaced by Argon lasers producing continuous blue-green light of 514 nm which possess the benefit of having selective absorption by hemoglobin.

25 The Argon laser is now an established instrument for the treatment of retinal detachment, sealing of retinal holes, diabetic retinopathy, avascular proliferation and hemorrhage. The Krypton laser, producing continuous red light at 647 nm, has been used in iris surgery, and shows promise in macular treatments. Carbon dioxide lasers producing continuous infrared radiation at 10.6 microns, used in general surgery, have also been tested for eye surgery. A major disadvantage of carbon dioxide lasers is that mechanical penetration is required because far-infrared light is completely absorbed by the cornea and all other ocular tissues.

40 The Argon photocoagulators have several shortcomings that make them unsuitable for certain surgeries in the eye. For example, white or transparent structures cannot be cut, because of their low absorption of green light. Photocoagulators also give rise to large areas of scar tissue, as a result of thermal effects. Pulsed Nd:YAG lasers utilize the effects of dielectric breakdown (ionization) created by the focusing of high power pulses of near infrared light and subsequent hydrodynamic shock to disrupt the desired tissue. The Nd:YAG laser has been under investigation for the last five years in ophthalmology. Since ionization and shock wave propagation are the cutting mechanism, even transparent structures such as the capsular membrane of the crystalline lens can be cut noninvasively. For further background, reference may be made to J. Haut, C. Imbert, F. Berny-Martin et al., "Clinical Studies on the Efficiency of High Power Laser Radiation Upon Some Structures of the Anterior Segment of the Eye", "Int. Ophthalmol." 3:129-139, 1981; M. M. Krasnov, "Q-Switched Laser Goniopuncture", "Arch.

Ophthalmol." 92 (July):37-41, 1974; D. Aron-Rosa, J. Griesmann, J. Aron, "Use of a Pulsed Neodymium YAG Laser (Picosecond) to Open the Posterior Capsule in Traumatic Cataract: A Preliminary Report", "Ophthalmic Surg.", 12:496-499, 1981; F. W. Fankhauser, P. Roussel, J. Steffen et al., "Clinical Studies on the Efficiency of High Power Laser Radiation Upon Some Structures of the Anterior Segment of the Eye", "Int. Ophthalmol." 3:129-139, 1981.

There are various patents describing laser systems for use in the field of ophthalmology. U.S. Patent No. 3,703,176 describes a slit lamp photocoagulator. U.S. Patent No. 3,828,788 describes a laser ophthalmoscope, U.S. Patent No. 4,309,998 describes a process and apparatus for ophthalmic surgery, Patent No. 3,971,382 describes a method of non-surgical treatment of cataracts using a laser beam, No. 4,122,853 shows an infrared laser photocoagulation system, and No. 3,710,798 describes a laser system for microsurgery.

90 Typical pulsed laser energy control systems operate by monitoring the energy output and then manually controlling the voltage on the flash lamp capacitor bank. The operator makes the measurement and physically adjusts the charging voltage for the capacitor bank. Closed loop laser systems for some uses are known which automatically set the charge voltage based on the measurement of output power or energy. U.S. Patent No. 3,806,829 shows a laser machine tool in which the output beam is monitored and the capacitor bank voltage is varied as necessary. In such systems the operator measures the laser pulse energy indirectly by measuring capacitor charge or places a meter external to the instrument, and the operator adjusts the output to the desired level. These are crude methods of adjustment, particularly in a surgical environment. Furthermore, there is a primary disadvantage in varying the capacitor bank voltage because there results a lack of stability of the laser energy pulses over the entire range of laser outputs, especially at low energy levels due to uneven ionization of the flashlamps. In most applications the energy range is restricted, generally to higher energy where pulse to pulse stability is relatively good.

Accordingly, it is a principal object of the present invention to provide an improved form of laser system, which is particularly useful for laser surgery.

Advantageously, the laser system is such that the output of a treatment laser in the system can be continually measured and the energy of the laser beam adjusted to maintain it within a desired energy range.

According to the present invention, there is provided a laser system and a method of laser operation which are particularly useful for

laser surgery, also a shutter for blocking a laser beam and a table assembly for use with a laser system, as defined in the appended claims.

- 5 In an embodiment of the laser system of the present invention, which will be described in greater detail after this summary, an Nd:YAG Q-switched laser produces short pulses of laser energy and the beam is focused on the tissue of the eye to be cut. The beam can be focused to a spot size of less than 0.05mm and the subsequent optical breakdown produces a high pressure wave that disrupts the tissue without detectable heating or other known adverse affect to the surrounding tissue. The optical delivery system further employs a red helium/neon (He:Ne) laser for aiming or viewing purposes. A delivery system is attached to the familiar slit lamp so as to allow the beam to be positioned on the target tissue. The combined beams, namely the treatment beam and the aiming beam, are coincident with that of the microscope of the slit lamp.
- 25 A typical application of the laser is the removal of a secondary cataract pupillary membrane. In this case, the He:Ne aiming beam is used to identify the treatment site and to focus on the membrane. Once the treatment site is chosen, the treatment laser is fired to open the membrane. The slit lamp is then focused on the next treatment site and the treatment laser again fired. The cut membrane typically tends to withdraw out of the visual field. The treatment of a thin pupillary membrane may typically require seven to ten pulses of 3 to 5 millijoules. The slit lamp can easily be repositioned for each succeeding pulse, and the details of each treatment (energy level, number of pulses, and so on) can be automatically recorded in a patient file. Another typical use of the present laser system is to disrupt pupillary strands. The He:Ne aiming beam is focused on the strand, and the treatment beam is generated. The present system can also be used for iridectomy procedures, or the cutting of other vascular tissue through the use of a thermal mode (Q-switch operation is suppressed) which provides some photocoagulation effects.

- 50 With a closed loop system, the operator or physician can preprogram a desired energy level, and the system can accurately maintain this level throughout the treatment procedure inasmuch as each laser pulse can be monitored and the energy level be promptly adjusted.

- 60 It is desirable to run the laser head of a system of this nature at a fixed energy level since a flash lamp pumped laser is most stable at one energy level, and because it is impractical and inefficient to vary the energy of the laser head itself. In accordance with the present invention, a laser beam attenuator is used to controllably attenuate the treatment

- 70 laser beam. A portion of the treatment beam can be monitored and used essentially in a closed loop or feedback loop to control the setting of the attenuator. This enables the energy of the beam to be repeatable and for beam energy to be maintained constant. A more accurate and reliable system can be provided as contrasted to those which vary the capacitor voltage. It should be noted that use of an attenuator presents the problem of what to do with the energy that is not used. There is a significant secondary reflection which may be as high as eighty percent of the total energy produced. The present system uses a beam dump for absorbing the reflected energy to prevent unwanted collateral radiation in the system and possible damage to the laser. The system of the present invention has good stability over the range from .25mJ to 200mJ.

- 85 The Neodymium YAG (Nd:YAG) solid state laser used in the present system uses trivalent Neodymium ions ( $Nd^{3+}$ ), which are selectively added to an Yttrium Aluminum Garnet (YAG) crystal. The laser light is produced by populating various electronic energy levels of the crystal. This population phenomena is accomplished by the use of a high voltage krypton flash lamp which produces light in the 700 to 400 nm region, needed to excite the electrons to a higher energy level, thus populating that level. Subsequently, the electrons lose their energy and effect a stimulated laser emission at 1064 nm (near infrared). Known Q-switching techniques are used to obtain intense (high instantaneous power) short pulses from the laser. Q-switching works by degrading the optical resonator gain (or Q) during pumping so that the energy inversion can build up to a very high value without laser oscillation. When the inversion reaches its peak, the Q is restored suddenly to its former high value. This causes an extremely rapid buildup of the laser oscillation and a simultaneous exhaustion of the inversion. Typically, these pulses are 2-30 nanoseconds, as opposed to the 500 microsecond pulses produced by non-Q-switched, termed "free running", lasers.

- 115 The laser head uses an electro-optic crystal as a Q-switch which functions as a voltage controlled gate inside the optical resonator. During the pumping of the laser, a high voltage is applied to the electro-optic crystal, and introduces a relative polarization phase shift of the linearly polarized laser electric field. Thus the light is blocked by the polarizer. In order to achieve maximum output, the Q-switch opening is timed to coincide with the energy inversion maximum. With respect to further background concerning lasers reference may be made to A. Yariv, "Introduction to Optical Electronics", New York, Holt, Rinehart and Winston, Inc. 1971.

- 130 With respect to shockwave formation in this

system, the focused treatment beam has sufficient electrical field strength to achieve dielectric breakdown. Short pulses of light with sufficient peak power density then force the electrically neutral atoms into an ionized state. Once in this state, the light pulse is strongly absorbed by the electrically conductive ions which are then heated by the electrical conduction. The important aspect is that the heating effect is limited to the region of dielectric breakdown. Through the sudden high temperature rise of a small volume, it is hypothesized that a hydrodynamic shock wave is formed, and propagates spherically. The mechanism of tissue disruption of the surrounding issue is thought to be mechanical compression induced by the shock wave. See J.F. Ready, "Effects of High Power Laser Radiation" New York, Academic Press, 1971.

The process of tissue disruption avoids the creation of scar tissue or denatured tissue that is produced by cutting utilizing thermal processes, such as with the photocoagulator lasers. By virtue of the fact that the beam is not absorbed by transparent tissues traversed, the damage is restricted to the region of dielectric breakdown, so the adjacent tissues are not cut. This tissue cutting method does not photocoagulate. The cutting of vascular tissue requires use of a mode with longer pulse duration and lower peak power density to yield coagulation through thermal effects. See F. W. Fankhauser, P. Roussel, J. Steffen, et al., *supra*.

The foregoing and other objects and features of the present invention will become better understood through a consideration of the following description taken in conjunction with the accompanying drawings in which:

Figure 1 is an overall system block diagram of an embodiment of the laser system of the present invention;

Figure 2 illustrates in greater detail shutters used in the system, with Figure 2a comprising a cross-sectional view of a shutter, Figure 2b a partial front view of the shutter, and Figure 2c the shutter plate used in the shutter;

Figure 3 provides further details of a beam attenuator used in the system, with Figure 3a showing a schematic of the beam attenuator and beam dump and a cross-sectional view of an energy meter, and Figure 3b showing a front view of an optical stage used in the attenuator;

Figure 4 is a cross-sectional view of a periscope of the delivery optics used in the system;

Figure 5 provides further details of the delivery system, with Figure 5a showing a perspective view of the slit lamp/microscope assembly and Figure 5b providing a perspective view of X-Y table for enabling convenient positioning of the delivery optics.

### 65 System

Turning now to the drawings, and first to the system block diagram of Figure 1, a laser head 10 and its associated control electronics 11 and power supply 12 for providing a treatment beam are shown. The laser head preferably is an Nd:YAG laser as noted earlier, and may be of the type shown in U.S. Patent No. 4,310,808 and No. 4,342,113. The optical path of the treatment laser 10 includes a shutter 14, beam attenuator 15, beam splitter 16, beam combiner 17, system shutter 18, and delivery optics 19. As will become apparent subsequently, the shutter-14 is used to block and off the Nd:YAG beam, the beam attenuator 15 is controllable to selectively attenuate the Nd:YAG beam, and the beam splitter 16 enables a small portion of the Nd:YAG beam to be diverted to an energy meter 22. The energy meter provides signals by a line 23 to a control computer 24, and the computer 24 controls the amount of beam attenuation by signals applied by a line 25 to the beam attenuator 15.

Continuing on with the optical path, the Nd:YAG beam passes from the beam splitter 16 through the beam combiner 17 to the system shutter 18. An aiming or viewing laser 30 provides a beam through a beam expander and polarizer 31 and shutter 32 to the beam combiner 17. The laser 30 preferably is a He:Ne laser which provides a beam observable by the doctor or operator of the system. This beam is combined via the beam combiner 17, and the combined treatment and marker beams 164 pass to the system shutter 18 and from there to the delivery optics 19. The combined beams are passed by the delivery optics 19 as indicated at 34 to the eye of the patient through the usual but modified slit lamp system as will be described in greater detail subsequently.

Considering the closed loop system aspect of the present invention further, the YAG shutter 14 is opened and the YAG laser 10 is fired against a closed system shutter 18. The system includes CRT display 38, as well as a keyboard 39 for entering instructions, a foot switch 40 for firing the treatment laser 10, and printer 41 for providing a hard copy of treatment parameters for use in any given treatment. The foot switch 40 is depressed and the laser is fired, and the infrared radiation pulse energy is detected by the energy meter 22. The resulting electrical signal proportional to the radiation energy is connected to the computer 24 where the signal is converted to a digitized voltage level representing the integrated pulse waveform detected by the meter 22. The meter 22 preferably uses a silicon photodiode as a detector. Only a small fixed fraction 145 of the total treatment laser energy pulse 126 is measured so as to prevent damage or saturation of the detector. The detected energy level is compared in a conventional manner in the computer 24 against

a suitable calibration table for the beam attenuator 15. The calibration table is a suitable table of numerical values which relates the amount of energy that passes the beam attenuator 15 to each of several attenuator settings and will be described in more detail in the discussion of Figure 3. Another YAG laser radiation pulse is fired and the energy again is measured by the meter 22 and compared against the calibration table. If the measured energy is within a preset tolerance (such as, three percent), the computer 24 can then allow the system to indicate through the CRT 38 that the calibration check is completed, and allows the system to enter the operate mode enabling pulses to exit the shutters and be delivered to the patient.

The operator selects suitable settings for the operation at hand by entry through the keyboard 39. For example, parameters are energy level, number of pulses to be generated, and the like, as selected by an attending physician when the system is in use for laser surgery. The selected parameters enable the system to produce treatment pulses through the delivery optics 19 to the patient. The operator then causes treatment pulses of the specific selected energy to be emitted by depressing the foot switch 40. The specific operating parameters for each set of machine settings can be stored by the computer for each patient, preferably on a floppy disc, and can be recalled as needed for display on the CRT 38 or printed by the printer 41. The CRT and keyboard thus allow entry of data, review of data, call-up of patient files, review of system status, patient file manipulation, summaries, and the like.

By use of a closed loop system including the beam splitter 16 and energy meter 22, each treatment pulse is monitored and recorded not only during calibration, but also during treatment. This insures that the proper energy level, number of pulses and total energy as selected by the physician and operator are provided during the treatment and recorded.

Considering the laser system components and operation in greater detail, the system is powered from conventional 240 VAC line power as indicated at 50 which is connected to a power relay 51. Preferably, the power relay is controlled by a key switch 52 so as to provide controlled and limited access to use of the system. Power is supplied from the power relay 51 to a line monitor 54 which is connected to the computer 24 so as to allow the computer to continually monitor the supply voltage to insure that it is within safe operating limits. Power also is provided to the power supply 12 of the treatment laser system 10-12, and the power supply 12 is an energy storage capacitor bank which is charged and subsequently discharged under control of the laser control electronics 11 to krypton flash

tubes for energizing or pumping Nd:YAG laser 10.

Safety interlock control electronics and emergency shutoff are diagrammatically shown at 58 and 59 and as connected via a line 60 to the computer 24, via a line 61 to the control electronics 11 and power relay 51, and via a line 62 to the system shutter 18. This safety system includes suitable proximity switches on removable panels (not shown) to indicate that a panel door or doors of the equipment are open, the power supply, 12 has exceeded safe temperature limits, and the like. The purpose of the safety interlock and emergency shutoff is to inhibit operation of the YAG control electronics 11, turn off the power relay 51 and close the system shutter 18, as well as indicate any such unsafe condition to the computer 24 which will display the condition and operator prompt on the CRT display 38. The computer 24 also is diagrammatically shown as connected via a line 64 to the laser power supply 12 and via line 65 to the control electronics 11. These connections are exemplary of various connections to and from the computer 24 for allowing numerous conditions of the system to be monitored to insure that voltages and the like are within predetermined safe limits, and that various components of the system are properly functioning. For example, the computer 24 can monitor the voltage of the capacitor bank in the power supply 12 and the excitation voltage for charging the capacitors via the line 64, and can shut off the power to the supply 12 if an unsafe condition occurs. It can monitor conditions of the control electronics 11, such as the flash lamp is enabled and ready to fire, the flash lamp is triggering, the Q-switch is enabled, and the like. Furthermore, the system can include a self-check or diagnostic program which is initiated when line power is first applied to check out system voltages, operating parameters, and the like before the power relay 51 is caused to close by the computer.

The shutters 14, 18 and 32 are connected with the computer 24 by respective lines 68, 69 and 70. These connections enable the computer to send a signal to each of the shutters to cause the respective shutter to open or close as is appropriate, and a feedback signal is provided to the computer to indicate that the shutter has moved to the selected open or closed position. The line 25 from the computer to the beam attenuator 15 supplies a control signal to the beam attenuator as noted earlier to set the amount of attenuation. A line 72 can provide a signal from the attenuator to the computer to indicate whether or not the attenuator is shifting to a new attenuation position as directed by the computer and as will be described in more detail in the discussion of Figure 3. All systems of the laser preferably are measured for

proper performance whenever the laser is fired, such as Q-switch voltage, flash lamp voltage, flash lamp triggered, and the like. An IBM 5150 personal computer has been found suitable for the computer 24 used with Techmar Lab Master board for Converting analog to digital and digital to analog signals and a Techmar Baseboard for single bit control and monitor digital signals. In addition a custom interface board provides signal conditioning for noise immunity, using standard techniques and logic for emergency shutoff 59 in the case of computer failure.

### 15 Shutters

Turning now to Figure 2, the shutters 14, 18 and 32 may be all alike and of the type shown in Figure 2. the purpose of the shutter is to completely block or pass the laser beam, be it the treatment beam from the laser head 10, the aiming beam from the laser head 30, or the combined beam from the combiner 17.

The shutter of Figure 2 need only be energized when it is necessary to shift from one position to another (from open to closed or from closed to open) and thus does not require power when it is in one of these two positions. A different part of the shutter is used for each successive off or closed position to minimize damage and deterioration of the shutter.

The primary component of the shutter is a circular aluminum plate 90 and ring of black Delrin plastic 91. Both have a series of circular holes or apertures 92 through which the laser beam may pass, and solid areas 93 between each such aperture. The plate assembly 90-91 is rotated by a stepping motor 96 in thirty degree increments. Recesses or other suitable depressions 97 are provided in the side of a hub 114 to allow a microswitch 98 to sense the position of the plate assembly 90-91 and to provide a signal back to the computer 24 of Figure 1 to indicate and therefore confirm that the shutter is in the proper open or closed position.

Considering the shutter assembly of Figure 2 in greater detail, the stepping motor 96 may be a Ledex stepping solenoid, and the same is attached to a housing 101 having a front cover 102 and a back cover 103 with respective apertures 104 and 105 through which the laser beam passes as indicated by an arrow 106 when the shutter is open. The shaft 108 of the solenoid 96 is connected to a first gear 109 which in turn is meshed with a second gear 110 disposed on a shaft 111. The shaft 111 is disposed in suitable bushings in the housing 101. The purpose of the gears 109 and 110 is to transmit the motion from the shaft 108 of the solenoid 96 to the plate assembly 90-91 and to reduce the size of the shutter package. It will be seen from Figure 2a that the gear 110 is keyed by a pin 113 to a hub 114 of the plate 90. This

arrangement causes the plate 90 and ring 91 to be rotated by the stepping solenoid 96.

The plate 90 for an exemplary shutter may be approximately three inches in diameter and approximately one-sixteenth inch thick. The holes 92 may be one-half inch disposed sixty degrees apart. The Delrin ring 91 preferably is approximately one-eighth inch thick, and is secured to the plate in any suitable manner as by several screws or the like. The Delrin ring transmits IR, but it is opaque to visible radiation. The laser beam strikes the Delrin ring 91 when the shutter is closed, and the mechanical energy of the beam is absorbed by the ring 91 and the IR energy is stopped by the aluminum plate 90. If only an aluminum plate 90 were used, it would electrically conduct due to the intense IR energy and eventually deteriorate or break down.

The microswitch 98 is suitably mounted within the housing 101 and arranged to detect the open (or closed if desired) position of the shutter by detecting the detents or depressions 97. Any other suitable microswitch or proximity sensor can be used to determine when the shutter is open to the laser beam.

It thus will be understood that the stepping solenoid 96 receives signals from the computer 24 of Figure 1 to cause the plate assembly 90-91 to step in thirty degree increments to open or close the shutter, and an indication of whether the shutter is closed or opened is provided by a signal from the microswitch 98 back to the computer 24.

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### Beam Attenuator and Energy Meter

The treatment laser beam passes from the laser head 10 through the open shutter 14 to the beam attenuator 15 as noted earlier. Further details of the beam attenuator 15 are shown in Figures 3a-3b, and further details of the energy meter 22 are shown in Figure 3a. In Figure 3a, the treatment beam 120 from the laser head 10 passes the ND:YAG shutter 14 and goes to the attenuator 15. The attenuator 15 includes a half wave plate 122 which is mounted for rotation in an optical stage 123 shown in Figure 3b and which will be described in more detail subsequently. The half wave plate 122 upon rotation rotates the field vector of the laser beam 120 and thereby changes the plane of polarization of the beam. The resulting beam 124 passes to a polarizer 125 which passes part of the beam 124 as indicated at 126 and reflects part of the beam as indicated at 127 to a beam dump 128. The amount of reflected energy 127 is a function of the plane of polarization of the beam 124 as determined by the position of the half wave plate 122. The half wave plate 122 may be plate WPM-10-10-2 sold by CVI of Albuquerque, New Mexico. The polarizer 125 may be a thin film dielectric polarizer TFP 3-4 by CVI and it is disposed at Brewster's angle. The beam dump 128 comprises

KG3 Schott glass 132 mounted in a Lexan plastic base 133. The beam attenuator comprising the halfwave plate 122 and the polarizer 125 basically is a beam splitter used as an attenuator, and the same is able to perform the attenuation function even at the relatively high energy levels of the beam 120. The beam dump 128 is used to absorb the reflected energy. If the reflected energy were reflected back into the laser 10, standing waves would result and the laser likely would be destroyed.

The halfwave plate 122 is mounted in a support ring 136 of the rotary stage 123. This rotary stage may be a No. 25120 rotary stage sold by Daedal, Inc. The support ring 136 is coupled to a disc 137 which has peripheral teeth 138 driven by a worm gear 139 which is rotated by a stepper motor 140. Thus, signals applied to the stepper motor 140 by via the line 25 (Figure 1) from the computer 24 cause the halfwave plate 122 to be rotated to change the plane of polarization of the resulting laser beam 124 (Figure 3a). The computer 24 can monitor the stall current of the stepper motor 140 via the line 25 so as to provide an indication when the plate 122 is being rotated. (or a separate feedback signal can be provided by line 72 of Figure 1). During manufacture and calibration of the present system, the treatment beam is fired through the halfwave plate 122 of the attenuator 15 for various rotational positions (e.g., 0 degrees—20 degrees) of the plate 122 and tions resulting passed laser energy measured for each position as explained previously. Typically .05 degree steps over a 0 degree to 20 degree range (400 stepper motor steps) are suitable. This allows the calibration table noted earlier in the discussion of Figure 1 to be generated in a simple manner.

The resulting beam 126 passes to the beam splitter 16 which reflects a majority of the beam as a treatment beam 144 and passes a small (e.g., one one-thousandth) of the beam as a measurement beam 145. The beam splitter is a dielectric mirror, such as No. Y1-1025-45 by CVI. The beam splitter 16 is suitably coated to reflect the IR beam 144. Only a small fraction of the treatment laser beam is needed for measuring the energy thereof, and it is not desirable to pass the entire powerful treatment beam, which may be as high as twenty-five megawatts, to the meter 122 since this would damage the energy meter. Also, it is desirable to continuously monitor the treatment beam during treatment and, thus, the entire beam cannot be diverted to the meter.

The beam 145 passes through a focusing lens 148, two Schott filters 149-150, and an aperture plate 151 to a silicon photodiode 154 in a suitable housing 158 of the meter 122. The diode 154 is mounted on a circuit board 155 and backed by a shield plate 156.

The filters 149-150 are selected to pass only IR and to exclude the incoherent collateral visible radiation resulting from the laser flash lamps, and to further attenuate the energy applied to the diode 154 preferably to approximately ten watts. The silicon diode 154 is connected to a suitable integrating circuit (not shown) to integrate the energy with respect to time and to a suitable analog to digital converter to provide a digital signal to the computer 24 of Figure 1 to indicate the energy of the treatment beam. If desired, the gain of the energy meter 22 may be adjustable in two or more ranges so as to obtain expanded precision when the treatment beam is at a low energy level (because of attenuation by the beam attenuator 15) so as to provide precision control at low energy levels required of some ophthalmology procedures.

The treatment beam 144 passes on to the beam combiner 17 (Figure 1) where the He:Ne beam is combined with the Nd:YAG beam. The combiner 17 is a substrate with a dichoric coating and may be a PW 1025C sold by CVI. The combiner is coated on side 17a to reflect greater than 90.4 degrees at 632.8nm and to reflect 75-80 degrees in S polarization and to reflect 85-90 degrees in P polarization at 1.06 microns. The second side 17b is coated ARAR at 1.06 microns. The resulting beam 164 is passed through the shutter 18 (when open) to the delivery optics 19.

#### 100 *Delivery Optics*

The delivery optics 19 include a movable X-Y table assembly for allowing positioning of the laser beam and viewing by a doctor with respect to a patient's eye as shown in Figure 5, and a periscope as shown in Figure 4. The combined treatment and marker beam 164 passed by the shutter 18 is reflected by mirrors of the movable table assembly as will be explained later as a beam 165 to a first mirror 170 of the periscope as shown in Figure 4. The beam 165 passes through a pivot tube 171 which allows the periscope assembly to be rotated as desired by the operator or physician. The mirror 170 is held by a mirror holder 172 mounted in a lower body 173 of the periscope. A similar mirror 174 is mounted in a holder 175. The beam 165 is reflected by the first mirror 170 to the second mirror 174, and from there through a first lens 178 of a beam expander. An expander tube 179 is coupled to the lower body 173 and contains a lens 180 in a lens holder 181. A columnator tube 183 is connected with the holder 181 and contains a lens 184. An element holder 185 is coupled to the columnator tube 183 and supports a final mirror 186 and provides a lens aperture 187 of the delivery optics. The mirrors 170 and 174 are coated to reflect IR and both may be NRC 07D10 mirrors sold by Newport Re-

search, Fountain Valley, California. The lens 178 of the beam expander may be a 01LDR007 by Melles Griot, and each of the lenses 180 and 184 may be 01LDX169 by Melles Griot. The beam expander expands the combined treatment and aiming beams and creates a relatively wide (approximately 40mm) columnated beam which is suitably focused by 184 and subsequently reflected by the final mirror 186 to the eye of the patient. The final mirror 186 may be a two inch dielectric coated mirror one-fourth inch thick CVI Y1-20-45. The first side 186a is coated to reflect at 1.06 microns at forty-five degrees incidence, and the second side 186b is coated ARAR for 632.8nm.

#### *Slit Lamp and X-Y Table*

Turning now to a more detailed discussion of the delivery optics 19 shown diagrammatically in Figure 1, Figure 5a is a simplified perspective view of a slit lamp assembly 6 including a conventional slit lamp microscope 196, slit lamp illuminator assembly 197, and patient chin rest 198 all mounted to and movable with a shroud 199. This assembly further includes the periscope 168 of Figure 4 coupled to and movable with the slit lamp assembly. Figure 5a further illustrates a table 202 which supports the slit lamp assembly as well as the CRT 38 and keyboard 39. The table may be mounted on suitable legs and have associated therewith an appropriate cabinet or cabinets for housing the electronics, floppy disc storage, printer, and the like.

The delivery optics, and specifically the periscope 168 of Figure 4 is arranged to be movable in an X-Y direction so as to allow the laser aperture 187 of the periscope 168 to be moved back and forth and sideways with respect to the patient's eye, and the periscope also is arranged to be rotatable about the pivot tube 171 (Figure 4). This allows the physician to move the microscope as well as the periscope in a manner familiar to the physician. An X-Y table assembly as shown in Figure 5b is disposed beneath the shroud 199 of the slit lamp assembly and affixed to the table 202 to allow the periscope 168 of Figure 4 and slit lamp to be moved together in the X and Y directions under control of a slit lamp control or "joy" stick 204. As will be apparent to those skilled in the art there are difficulties in providing such movement inasmuch as it is necessary to maintain the integrity of the laser beam path. As will be seen from Figure 5b, the laser beam 164 emanating from the beam combiner 17 and system shutter 18 (of Figure 1) is directed at a first mirror 208 mounted on a "Y" axis plate 209, which plate is movable in a "Y" direction as indicated by arrows 206, and a second mirror 210 is mounted on an "X" axis plate 211 arranged to be moved in an X direction as indicated at 205. The plate 211

extends upwardly through a rectangular hole 238 in the plate 209. The mirrors 208 and 210 may be Newport Research Corporation substrate 10D20 with an ER.2 coating. The detailed structure of the X-Y table will be discussed later.

The mirror 208 reflects the laser beam (the combined YAG and He:Ne beams) ninety degrees as a beam 213 toward the second mirror 210 which, in turn, reflects the combined beam ninety degrees as beam 165 upwardly through a hole 215 in the X axis plate 211. The pivot tube 171 of the periscope 168 shown in Figure 4 is suitably mounted with respect to the hole 215 in the "X" plate 211 and, thus, the beam 165 from the mirror 210 of the X-Y table assembly is directed upwardly through the pivot tube 171 to the first mirror 170 of the periscope 168 as previously discussed in connection with Figure 4. As will be apparent to those skilled in the art, the Y axis plate 209 can be moved back and forth along the Y axis 206 while the first mirror 208 of the table assembly properly reflects the incoming combined laser beam 164 to the second mirror 210. Likewise, the X axis plate 211 can be moved back and forth along the X axis 205 while still allowing the second mirror 210 to receive the beam 213 from the first mirror 208 and reflect beam 213 upwardly as beam 165. Similarly, the periscope 168 (Figure 4) can be rotated about the pivot tube 171 with respect to the hole 215 in the X axis plate 211 to allow the periscope to be rotated with respect to the plate 211 and with respect to the patient's eye while still properly receiving and directing the combined laser beam 165. This table assembly accordingly allows the periscope 168 to be appropriately moved in the X and Y directions and to be rotated with respect to the patient's eye in a manner familiar to the operator or physician without requiring complicated or cumbersome articulated arms and the like for providing the laser beam to the patient.

Considering the X-Y table structure in greater detail, the same includes a stationary cover plate 220 which is affixed to the table 202.

The cover plate 220 has a rectangular hole 221 and the Y axis plate 209 has a rectangular opening 236 through which the X axis plate 211 is affixed to the shroud 199 by suitable brackets 237 and 239 to thereby allow the shroud to move with the X axis plate. The Y axis plate 209 is mounted in bearing blocks and bearings 222 through 225, and the bearings of 222-223 are mounted on a shaft 227 which, in turn, is supported in outer block supports 228 and 229 affixed to the underside of the cover plate 220. Similarly, the bearings of 224-225 are mounted on a shaft 231 which is supported by support blocks 232-233 affixed to

the underside of the plate 220. Cushions, such as a cushion 235, preferably are provided at the end of each shaft of the table assembly. It will be apparent that the Y axis plate 209 can be moved back and forth along the Y axis as indicated by the arrows 206 with respect to the plate 220.

The X axis plate 211 is mounted onto the Y axis plate 209 in a manner similar to the way the Y axis plate 209 is mounted to the plate 220. Thus, the X axis plate is affixed to bearing blocks and bearings 240-243 and the bearings of 240-241 are mounted on a shaft 245 and the bearings of 242-243 are mounted on a shaft 246. The shaft 245 is secured to inner block supports 248-249 which are affixed to the underside of the Y axis plate 209, and the shaft 246 is affixed to a similar pair of support blocks, (only support block 251 being seen in Figure 5b), which likewise are affixed to the underside of the Y axis plate 209. Thus, it will be apparent that the X axis plate 211 can move back and forth in the X direction as indicated by the arrow 205, and extends upwardly from the Y axis plate 209 and through the rectangular hole 238 of the Y axis plate 209 and supports the shroud 199 through the hold 221 in the cover plate.

While presently preferred embodiments of the present invention have been illustrated and described, many modifications and variations thereof will be apparent to those skilled in the art given the teachings herein, and it is intended that all such modifications and variations be encompassed within the scope of the appended claims.

#### CLAIMS

1. A laser system comprising
  - laser means for emitting a treatment beam,
  - delivery optics means for delivering the beam to a treatment site,
  - beam splitter means in the optical path between the laser means and optics means for directing a portion of the beam to an energy meter for measuring the energy of the beam,
  - attenuator means in the optical path between the laser means and the beam splitter means for controllably attenuating the beam, and
  - control means responsive to the energy meter means for controllably adjusting the attenuator means to thereby control the degree of attenuation of the beam.
2. A system as claimed in Claim 1 wherein the optical path between said beam splitter means and delivery optics means includes system shutter means to prevent the treatment beam from the laser means from reaching the optics means until the energy level of the beam has been adjusted by the attenuator means.
3. A system as claimed in Claims 1 or 2 including

beam combiner means in said optical path arranged between said beam splitter means and system shutter means, and

- aiming laser means adapted to direct an aiming laser beam at the beam combiner means for providing a combined treatment and aiming laser beam to the optics means.

4. A system as claimed in Claims 1, 2 or 3 including

- display means and keyboard means connected with said control means for entering selected treatment laser beam energy levels and for displaying the same.

5. A system as claimed in any of Claims 1 to 4 wherein

- said beam attenuator means comprises a rotatable halfwave plate for changing the plane of polarization of the treatment laser beam and includes a polarizer, and
- beam dump means disposed for receiving radiation reflected by said polarizer.

6. A closed loop laser surgery system comprising

- laser means for emitting a treatment beam,
- delivery optics means for delivering the beam to a treatment site,
- shutter means disposed between the laser means and the delivery optics means for selectively allowing the beam to pass to the shutter means,

beam splitter means in the optical path between the laser means and delivery optics means for directing a portion of the beam to an energy meter for measuring the energy of the beam,

- attenuator means in the optical path between the laser means and the beam splitter means for controllably attenuating the beam, said beam attenuator means comprising means for changing the plane of polarization of the treatment laser beam and including a polarizer, and beam dump means disposed for receiving radiation reflected by said polarizer, and

control means responsive to the energy meter means for controllably adjusting the attenuator means to thereby control the degree of attenuation of the beam and for opening and closing said shutter means.

7. A system as claimed in Claim 6 including beam combiner means arranged between said beam splitter means and system shutter means, and

- aiming laser means adapted to direct an aiming laser beam at the beam combiner means for providing a combined treatment and aiming laser beam to the delivery optics means.

8. A system as claimed in Claims 6 or 7 including

- display means and keyboard means connected with said control means for entering selected treatment laser beam energy levels and for displaying the same.

9. A method of laser operation using deliv-

ery optics for delivering a laser treatment beam to a treatment site comprising generating a laser treatment beam and blocking the treatment beam from reaching the delivery optics while measuring at least a portion of the energy of the treatment beam and adjusting a treatment beam attenuator means disposed in the optical path of the laser to adjust the energy of the treatment beam,

repeating the step of generating the laser treatment beam and measuring a portion thereof, and adjusting the attenuator means until the laser beam is within a predetermined tolerance, opening said shutter means to allow the laser treatment beam to reach the delivery optics, and periodically measuring a portion of the energy of the treatment beam and adjusting the attenuator means as necessary to maintain the energy of the treatment beam within the predetermined tolerance.

10. A method as claimed in Claim 9 including

combining an aiming beam with said treatment beam before said treatment beam reaches the delivery optics.

11. A method as claimed in Claims 9 or 10 including

attenuating said treatment beam by changing the polarization thereof and reflecting a portion of the beam to a beam dump.

12. A shutter for blocking a laser beam comprising

a metal plate, a plastic ring adjacent the plate, the plate and ring having a plurality of substantially equally spaced holes and solid areas between the holes, the holes providing a path for passing a laser beam,

housing means for housing the plate and ring and for allowing the plate and ring to be rotated in a step-wise fashion, said housing means being adapted to support the plate and ring to allow a laser beam to pass through a hole in the plate and ring assembly, and means for rotating said plate and ring assembly.

13. A shutter as claimed in Claim 12, said housing means having an opening therethrough for allowing a laser beam to pass through the opening and to pass through a hole in the plate and ring assembly when a hole thereof is aligned with the opening in said housing.

14. A shutter as claimed in Claim 13 including

detector means for detecting the position of holes in the plate and ring assembly with respect to the opening in the housing and for providing an electrical signal indicative of the open or closed position of the shutter.

15. A shutter as claimed in Claims 13 or 14 wherein

said holes in said plate and ring are disposed at substantially sixty degree intervals, and

said means for rotating said plate and ring assembly comprises stepper motor means for advancing said plate and ring in thirty degree steps.

16. A table assembly for use with a laser system including a slit lamp and microscope assembly and laser delivery optics for directing a laser treatment beam as at treatment site, and wherein the table assembly allows positioning of the delivery optics with respect to the treatment site, said table assembly comprising

cover plate means adapted to be secured to a stationary support, said cover plate means having an opening therein,

Y axis plate means mounted for movement linearly in a Y axis direction with respect to said cover plate means, said plate means having a first mirror mounted thereon for receiving an input laser beam directed parallel to the Y axis, and said Y axis plate means having an aperture therein,

X axis plate means mounted for movement linearly in an X axis direction perpendicular to said Y axis direction on said Y axis plate means, said Y axis plate means including a second mirror mounted with respect to said first mirror for receiving the laser beam reflected by said first mirror and for further reflecting said laser beam up through an aperture in said X axis plate through said opening in said cover plate means, and

support means attached to said X axis plate means for supporting said delivery optics.

17. A laser system substantially as herein described with reference to Figure 1 of the accompanying drawings with or without features herein described with reference to Figures 2 to 5.

18. A method of laser operation using delivery optics for delivering a laser treatment beam to a treatment site, substantially as herein described with reference to the drawings.

19. A shutter for blocking a laser beam substantially as herein described with reference to the drawings, more particularly Figure 2.

20. A table assembly for use with a laser system, said assembly being substantially as herein described with reference to the drawings, more particularly Figure 5b.